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New progress on the correlation of Chinese terrestrial Permo-Triassic strata

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Summary

This paper reviews recent works on the age of Chinese terrestrial Permo-Triassic strata, mainly based on the isotopic dating and the tetrapod correlation. For the application of U-Pb dating methods for the stage-level division of Permo-Triassic strata, the best method is the Thermal Ionization Mass Spectrometer (TIMS), while the Secondary Ion Mass Spectroscopy (SIMS) can be used for many cases; however, the most popular Laser Ablation Inductively Coupled Plasma Mass Spectrometry (LA-ICPMS), which has nearly 4% error (>8 Myr), is of little use (Li et al., 2015).

The ages of major terrestrial strata are discussed for the Junggar Basin and Turfan-Hami Basin, the North Qilian area, the North China area, and the South China area.

Junggar Basin and Turfan-Hami Basin Yang et al. (2010) published some dating results that significantly changed the correlation of Permian strata in this area. The base of Permian lies within the Daheyan Formation. The Lucaogou Formation is moved from Guadalupian or Lopingian to Cisuralian in age. The Hongyanchi Formation is the Artinskian in age. There is a big time gap between the Hongyanchi and Quanzijie formations. The Quanzijie Formation possibly belongs to the Capitanian although Lucas (2001, 2017) insisted on a younger age. The Wutonggou Formation is Wuchiapingian in age. The transition from Permian to Triassic falls within the Guodikeng Formation based on the study of various fossil groups, but there is no clear cut position for the P-T boundary right now. The age of the Karamay Formation is unsure. The base of Jurassic lies at the top of the Haojiagou Formation (Lu and Deng, 2005) or within it (Huang, 2006).

North Qilian area The Qingtoushan Formation belongs to the Guadalupian (Roadian or Wordian) in age based on the Dashankou Fauna (Rubidge, 2005; Liu et al., 2009; Lucas, 2017). So, the underlying Yaogou Formation should be early middle Guadalupian or late Cisuralian. The dicynodont from the top of the Sunan Formation suggested a late Lopingian age (Li et al.,

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2000; Kammerer et al., 2011), while the flora from the lower part suggested Wuchiapingian (Sun K Q et al., 2010). There could be little Capitanian deposits at this area.

North China area The typical Permian and Triassic section in this area includes the Taiyuan, Shanxi (Shansi), Xiashihezi (Lower Shihhotse), Shangshihezi (Upper Shihhotse), Sunjiagou, Liujiagou, Heshanggou, Ermaying, Tongchuan, Yongping and Wayaopu formations.

The Taiyuan Formation includes both marine and terrestrial facies, and the base of Permian lies within this formation. Its upper portion is Artinskian in age based on conodont *Sweetognathus whitei* (Mei and Henderson, 2001; Wang and Qi, 2003). The Shanxi Formation is also Artinskian in age based on miospores (Liu et al., 2015). The Xiashihezi Formation is correlated to Kungurian to Wordian. The upper part of the Shangshihezi Formation was correlated with the *Cistecephalus* Assemblage Zone of South Africa, and it is estimated earlier than 255 Ma (Rubidge et al., 2013; Liu J et al., 2014). The P-T boundary is traditional put between the Sujiagou Formation and the Liujiagou Formation, or could lie within the Sunjiagou Formation (Yin and Lin, 1979). However, the latter hypothesis is not supported by the pareiasaur occurrence (Gao, 1983).

Our recent work indicated the base of Anisian (Lower/Middle Triassic boundary) could lie within Heshanggou Formation (Liu et al., 2018), as suggested by Rubidge (2005). The base of Ladinian roughly equals to the base of the Tongchuan Formation, and the base of Carnian lies above the top of the Tongchuan Formation (Wang et al., 2014).

South China area The terrestrial deposits in this area began from the Xuanwei Formation (Lopingian) in western Guizhou and east Yunnan (east margin of the Kangdian High). Kayitou Formation is a transitional unit both in age and facies. The P-T boundary lies within the Kayitou Formation for most if not all sections, and the Dongchuan Formation is Induan in age (Chu et al., 2016, 2017; Zhang H et al., 2016).

The Badong Formation has some terrestrial members such as Member II, which produced terrestrial tetrapod *Lotosaurus* and *Yuanansuchus* (Zhang, 1975; Liu and Wang, 2005; Liu, 2016). The Badong Formation is generally regarded as Middle Triassic in age, and there is no really advance on this.

The Xujiahe Formation produced diverse fossil plants and the oldest dinosaur footprints in China. It was dated as Rhaetian by the marine bivalve from underlying Xiaotangzi Formation. This result was confirmed by astronomical tuning and magnetostratigraphy (Li et al., 2017).

中国陆相二叠、三叠纪地层年代对比新进展

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摘要：总结了近10多年来陆相二叠、三叠纪地层年代的新认识，证据主要来自于同位素测年以及四足动物化石对比，集中介绍了新疆的准噶尔盆地和吐哈盆地、北祁连区和华北地

层区的新对比方案。新疆吐哈盆地同位素测年的结果证实红雁池组及以下的芦草沟组是乌拉尔统，泉子街组是瓜德鲁普统，仅梧桐沟组及锅底坑组是乐平统。红雁池组与泉子街组间存在很长沉积间断，而烧房沟组与克拉玛依组间也可能存在沉积间断。乌鲁木齐鲵时代与国外大多数西蒙螈类时代基本一致，是我国二叠纪最早的四足动物化石。由脊椎动物化石对比得知北祁连区的青头山组相当于瓜德鲁普统下部，而肃南组是乐平统，中间可能存在沉积间断。华北上、下石盒子组都可能包括了很长时代的沉积，上石盒子组延续到吴家坪阶上部；根据锯齿龙类化石，孙家沟组基本属于二叠系；二马营组二段下部243.5 Ma的年龄支持这个组时代为安尼期晚期；铜川组顶部还为拉丁阶，没有延伸到卡尼阶。

关键词：二叠系，三叠系，锆石铀铅测年，地层对比，四足动物化石

中国二叠纪和三叠纪时期的基本格局是北陆南海，北方的华北地块、塔里木地块以及北疆褶皱带以陆相沉积为主，而南方的华南地块和西藏地块以浅海碳酸盐沉积为主(Jin et al., 2000)。典型的陆相沉积盆地包括准噶尔盆地、吐哈盆地和鄂尔多斯盆地，有基本连续的二叠系和三叠系，产出丰富的各门类化石、油气和煤炭资源；研究深入，有经典的地层剖面。此外还有一些小型的沉积盆地，也有较好的沉积序列。经过上百年几代地质学家的研究，我国建立了陆相二叠纪和三叠纪地层初步的划分以及对比方案(Jin et al., 2000; Yang et al., 2000)。

近些年随着研究的进行，发表了一些新的地层对比结果，包括基于同位素测年数据的结果。这些发现推进了我们对于地层年代的认识。本文将评述目前采用的锆石铀铅(U-Pb)测年方法，并主要基于测年的结果总结2000年以来我国主要陆相二叠纪和三叠纪地层年代对比的新认识，同时指出存在的问题以及可能的进一步工作。

1 陆相地层高精度对比方法

陆相地层建立精细的年代地层框架是一个棘手的科学问题。二叠系和三叠系的阶都建立在海相地层中，而陆相地层与海相地层一般很难进行对比，这就造成同样的年代地层单位(如中三叠统)在陆相地层中使用时与定义的涵义往往并不一致。海陆对比的方法包括：在海陆相地层中寻找共同存在的化石，在陆相地层中寻找海相夹层，再利用里面的海相标准化石来对比，例如美国得克萨斯二叠系四足动物带与海相化石带的对比(Lucas et al., 2006)；也可以根据全球性的气候变化来对比海陆相地层(Krassilov and Karasev, 2009)；还可以利用同位素变化曲线，磁性地层学以及天文旋回地层等手段(例如Zhang H et al., 2016; Li et al., 2017; Lucas, 2017)；当然，最直接的方法是通过绝对年代的测定来进行对比。

对于阶一级的对比，需要测年达到一定的精度。目前二叠系和三叠系常用的地质测年手段有锆石U-Pb法以及透长石的$^{40}Ar/^{39}Ar$法。锆石U-Pb法目前主要有热电离质谱法(TIMS)、二次离子质谱法(SIMS)、以及激光剥蚀–电感耦合等离子体质谱法(LA-ICP-MS)。后两种方法由于成本低和分析速度快，得到了大量的应用。SIMS的结果的误差大约为1% (Schmitz and Kuiper, 2013)，对于二叠纪和三叠纪地层来说就是大约2–3 Ma的误差，在有些情况下能够解决对比问题。LA-ICP-MS的外部重现度(准确度)差，误差达

到大约4% (Li et al., 2015), 对于二叠纪和三叠纪地层来说就是大约8–12 Ma的误差，不能用于解决阶甚至统一级的地层年代问题。TIMS的精度单一晶体可以达到0.1%, 加权平均后达到0.03% (Schmitz and Kuiper, 2013), 对于二叠纪和三叠纪地层来说误差小于0.3 Ma以及0.1 Ma, 是足够精确的。目前最好的方法是化学侵蚀—热电离质谱法(CA-TIMS) (Mattinson, 2005), 它可以克服铅丢失，不过由于要求较高，能够用这种方法进行测年的实验室太少。$^{40}Ar/^{39}Ar$法只测量相对年龄，需要别的手段如K-Ar法来配合才能得出绝对年龄。

要在沉积地层中进行年龄测定，最好能够寻找到火山灰夹层中的矿物，否则只能尝试用碎屑锆石。火山灰中新形成锆石的年龄大致近似于沉积年龄，而碎屑锆石的最小年龄可以限定地层的最老沉积年龄。不过由于低温铅丢失，实际测得的单颗锆石的年龄可能小于沉积物的年龄(Nelson, 2001)。

此外，国外有些陆相地层已经建立了一些可供参考的年代框架，例如主要用CA-TIMS得出的南非卡鲁盆地二叠纪四足动物组合带的年龄(Rubidge et al., 2013), 美国出产恐龙化石的上三叠统的Chinle组的年龄(Irmis et al., 2011; Ramezani et al., 2011), 南美洲与恐龙相关的Chañares组(Marsicano et al., 2016)以及Ischigualasto组的年龄(Rogers et al., 1993; Martinez et al., 2011)。目前在南非Ecca群获得的年龄显著小于上覆的含二叠纪四足动物的Beaufort群的年龄(McKay et al., 2015), 不过古地磁以及古生物资料并不支持这一结论(Barbolini, 2014; Tohver et al., 2015; Belica et al., 2017)。我国经过多年的工作，初步建立了陆相二叠系和三叠系的四足动物序列(表1) (主要参考Li and Cheng (1995)及Li et al. (2008))。如果我国陆相地层能够根据化石，例如四足动物组合，与国外的地层建立对比，也可以得出地层的年代。

表1 中国陆相二叠系和三叠系所含四足动物序列大致对比表

Table 1 Correlation of Permian and Triassic terrestrial tetrapod assemblages of China

		新疆 Xinjiang	北祁连 North Qilian	华北 North China	华南 South China
中三叠世 T_2	拉丁期 Ladinian	*Xiyukannemeyeria* AZ		*Yonghesuchus*	
	安尼期 Anisian			*Sinokannemeyeria* AZ	*Lotosaurus-Yuanansuchus*
				Shaabeikannemeyeria AZ	
早三叠世 T_1		*Lystrosaurus* AZ			
乐平世 P_3	长兴期 Changsingian	*Turfanodon* AZ	*Turfanodon*	*Shihtienfenia* AZ	
	吴家坪期 Wuchiapingian			*Honania* AZ	
瓜德鲁普世 P_2					
	罗德期 Roadian		*Sinophoneus* AZ		
乌拉尔世 P_1					
	萨克马尔期 Sakmarian	*Urumqia*			

AZ: Assemblage Zone组合带。

2 地层时代讨论

以下就我国主要的陆相二叠系和三叠系，分新疆的准噶尔盆地和吐哈盆地、北祁连区、华北区以及华南区进行讨论。

2.1 新疆的准噶尔盆地和吐哈盆地

准噶尔盆地二叠系的传统地层划分自下而上包括下芨芨槽群、上芨芨槽群以及下仓房沟群。下芨芨槽群以半深海-陆棚的沉积为主，火山岩系发育，因此不在本文讨论范围。上芨芨槽群自下而上包括乌拉泊组、井井子沟组、芦草沟组和红雁池组。下仓房沟群自下而上包括泉子街组、梧桐沟组以及锅底坑组。吐鲁番盆地与上芨芨槽群相当的地层为桃东沟群，包括大河沿组和塔尔朗组，上覆也是下仓房沟群。塔尔朗组与芦草沟组和红雁池组相当，有研究者在吐鲁番盆地也使用后两个组。三叠系两地自下而上都是韭菜园组、烧房沟组、克拉玛依组、黄山街组和郝家沟组。天山南北这一时期的地层序列一般认为是大致同时的。

杨晚等人(Yang et al., 2010)在吐鲁番桃树园剖面的工作极大地改变了过去的看法。他们在大河沿组下部用$^{40}Ar/^{39}Ar$法、高分辨二次离子探针质谱法(SHRIMP)以及ID-TIMS进行测年，结果为早于300 Ma (图1①), 应该是上石炭统的格舍尔阶，本组上部可能能够到达萨克马尔阶之底(Yang et al., 2010)。大河沿组时代在《中国地层典》中被认为相当于船山统到阳新统下部。

芦草沟组最初是在1976年西北地层会议创名，1980年的《新疆北部中生代脊椎动物化石地层》中已经使用这一名词；因此不是如《中国地层典：二叠系》所言“1981年由新疆地层表编写组创名”。创名前沿革可以参见赵喜进(1980)表1。根据产出的古鳕类，其时代被认为是“晚二叠世”(Liu and Ma, 1973), 但是不排除包括“早二叠世”(Zhao, 1980)。根据大河沿组下段之顶301 Ma以及红雁池组顶部页岩中夹的火山灰281.39 Ma的ID-TIMS年龄(图1②), 推测其对应于中下萨克马尔期阶到亚丁斯克阶之底(Yang et al., 2010)。这样本组出产的六道湾乌鲁木齐鲵时代就与大多数西蒙螈类(Seymouriamorpha)的时代一致(Zhang et al., 1984)，而且还是我国二叠纪已知最老的四足动物。过去认为红雁池组时代是阳新世晚期，根据测年的结果应该大致相当于亚丁斯克期(Yang et al., 2010)。

泉子街组曾经被当作早三叠世的沉积，后来根据发现的植物、双壳类和四足动物确定为“晚二叠世”, 可能相当于吴家坪期(Jin et al., 2000)。赵喜进(1980)已经提出泉子街组与红雁池组之间为不整合接触，存在较长时间的沉积间断。不过这个间断常常被忽略为小间断。杨晚等人认为泉子街组时代大致相当于卡匹敦期。Lucas (2001)将泉子街组到锅底坑组发现的二齿兽类归并为*Dicynodon*, 从而认为其时代与南非的二齿兽带相当。按照最近的同位素测年结果，二齿兽带大约开始于255.2 Ma (Rubidge et al., 2013)。不过Lucas的归并未被广泛接受(Kammerer et al., 2011), 虽然最近他还是坚持自己的观点(Lucas, 2017)。在泉子街组报道过陡壁弓板兽(Sun, 1978), 但是其在二齿兽类中的系统位置还有待进一步研究，目前还不足以提供对比依据。按照杨晚等人(Yang et al., 2010)的观点，这个沉积间断大约有15 Ma。

根据梧桐沟组顶部的ID-TIMS测年结果(图1③), 本组基本是吴家坪阶的(Yang et al., 2010)。

锅底坑组上部产出水龙兽。水龙兽曾经长期被作为陆相三叠系开始的标志，不过后来在中国以及南非发现了水龙兽与二齿兽的共存(Cheng, 1993; Smith and Botha, 2005)。南非的二叠系和三叠系界线在很长时间内是以*Dicynodon*的消失，也就是二叠纪四足动物群的消失为标志(Smith and Botha, 2005; Ward et al., 2005)。不过最近在南非经典地点Old Lootsberg Pass发现的动植物化石以及这个界线下大约60 m处(253.48 ± 0.15) Ma的年龄表明这个界线可能比海相的界线要老一些，目前卡鲁盆地的二叠纪和三叠纪界线可能更高或者没有保存(Gastaldo et al., 2015)。不过有人认为这个剖面的二齿兽化石及火山灰层可能都是再沉积的，不可靠；此外最近的工作表明，卡鲁盆地远源侧的二叠系和三叠系界线未保存，而近源侧过渡层则保存更完整一些；而且以*Daptocephalus*的消失为三叠纪开始的标志(Rubidge et al., 2016; Viglietti et al., 2016)。根据对各种动植物化石的研究，二叠纪-三叠纪生物的面貌转换发生在锅底坑组，近些年提出的二叠纪-三叠纪的界线也在锅底坑组内部(Cao et al., 2008; Liu and Abdala, 2017)。目前还缺乏与海相地层进行更精确对比的有效手段。

韭菜园组，尤其是其中下部，盛产四足动物化石，属水龙兽带，其时代一般认为是早三叠世早期。烧房沟组化石稀少，目前依据其与韭菜园组相似的孢粉组合，将其时代归入早三叠世。它与下伏地层为假整合接触(Li et al., 1986)。近些年在本组发现了一个保存尚可的主龙型类化石，希望能够提供更多的年代对比信息。

因为对克拉玛依组顶底界有不同的定义，导致对其时代也有不同看法。按照赵喜进(1980)的观点，其与下伏烧房沟组为假整合接触，而李佩贤等则认为是整合接触(Li et al., 1986)。一般认为本组时代为中三叠世，而李佩贤等人(Li et al., 1986)根据孢粉研究认为，克拉玛依组下部可能是拉丁阶，上部可能包括上三叠统。最近史骁等人(Shi et al., 2014)也得出类似结论。赵喜进(1980)将1976年西北地层会议采用的的克拉玛依组的顶部产鱼的层位归入黄山街组，认为其时代是晚三叠世，主要依据是归入鹰龙类(aetosaur)的异地阜康鳄(*Fukangolepis barbaros*) (Young, 1978)以及长背鳍阜康鱼(*Fukangichthys longidorsalis*) (Su, 1978)的发现。不过异地阜康鳄其实是肯氏兽类的部分骨骼，因此不能说明问题；此外阜康鱼与晚三叠世的*Tanaocrossus*或者*Scanolepis*亲缘关系较远，故发现的脊椎动物并不能说明克拉玛依组时代包含了晚三叠世(Lucas and Hunt, 1993)。

在准噶尔盆地西北缘的克拉玛依组上段的时代定为晚三叠世，下段定为中三叠世晚期–晚三叠世早期(Luo et al., 2015)。这与南缘的沉积序列并不一致(见Luo et al., 2015), 可能时代也并不一致，不能用于讨论南缘地层的时代。

黄山街组化石丰富，有大植物、孢粉、昆虫和双壳类等。在吐哈盆地根据孢粉研究结果，其时代为晚三叠世(Yin, 1994)或晚三叠世早中期(Liu, 2001)。根据大植物化石确定的时代为卡尼期或者卡尼期到诺利期(Sun G et al., 2010)。

郝家沟组植物化石丰富。根据大植物化石确定其时代为晚三叠世，可能是诺利期到瑞替期(Sun G et al., 2010)。根据孢粉组合，卢远征和邓胜徽(2005)划分出两个组合：*Alisporites- Chordasporites-Chasmatosporites*组合和*Aratrisporites-Alisporites-*

*Chasmatosporites*组合，将侏罗系底界置于本组顶部 (Lu and Deng, 2005)。而黄嫔(2006)将卢远征和邓胜徽(2005)的下组合细分为两个组合，同时提出只有最底部为上三叠统，而上部为下侏罗统。

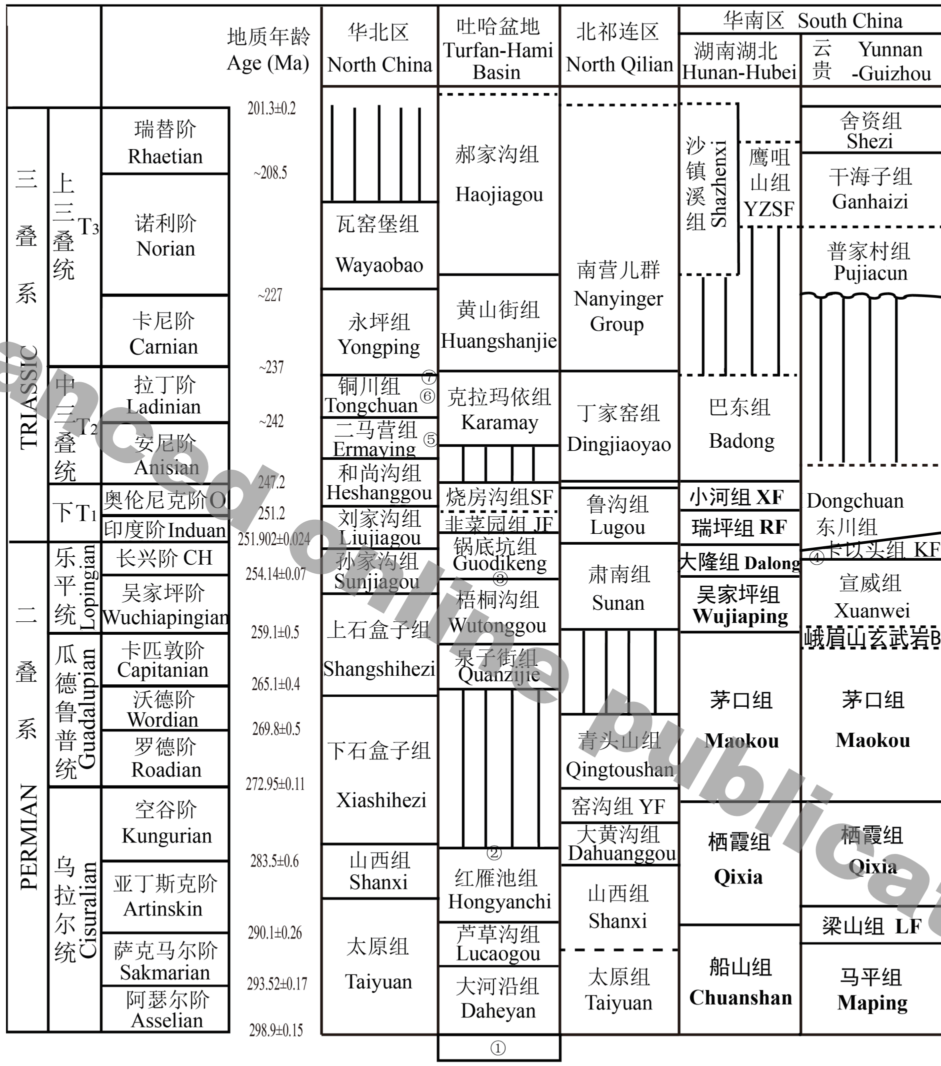

图1　中国典型含陆相地层二叠、三叠纪地层序列对比

Fig. 1　Correlation of typical Chinese Permian to Triassic terrestrial-bearing stratigraphic sequences

海相地层及玄武岩为黑体marine strata and basalt in bold; ①–⑦ 重要测年结果的层位 horizons with important dating result: ① 大河沿组Daheyan Formation(301.26±0.05) Ma, ② 红雁池组Hongyanchi Formation (281.39±0.10) Ma, ③ 梧桐沟组Wutonggou Formation (254.22±0.24) Ma, (253.63±0.24) Ma, (253.11±0.05) Ma (Yang et al., 2010); ④ 宣威组Xuanwei Formation (252.30±0.07) Ma (Shen et al., 2011); ⑤ 二马营组Ermaying Formation (243.528±0.069) Ma, (243.29±0.14) Ma, ⑥ 铜川组Tongchuan Formation (241.369±0.061) Ma, (241.482±0.074) Ma (Liu et al., 2018); ⑦ 铜川组Tongchuan Formation (241.3±2.4) Ma, (239.7±1.7) Ma (Wang et al., 2014). Abbreviations: B. Emeishan Basalt; CH. Changhsingian; KF. Kayitou Formation; JF. Jiucaiyuan Formation; LF. Liangshan Formation; O. Olenekian; RF. Ruiping Formation; SF. Shaofanggou Formation; XF. Xiaohe Formation; YF. Yaogou Formation; YZSF. Yingzuishan Formation

2.2 北祁连区

本区二叠系和三叠系包括太原组、山西组、大黄沟组、窑沟组、青头山组、肃南组、鲁沟组、丁家窑组和南营儿群(Jin et al., 2000; Yang et al., 2000; Liu et al., 2012)。这里的太原组和山西组与太原剖面的同名地层时代有差别。大黄沟组时代应该是乌拉尔世晚期(Sun et al., 1992)。窑沟组原来被认为是 “晚二叠世”, 不过其上覆的青头山组中发现了大山口动物群，时代为瓜德鲁普世(罗德期或者沃德期) (Rubidge, 2005; Liu et al., 2009; Lucas, 2017), 因此其时代暂定为瓜德鲁普世早中期，那么窑沟组时代可能就是乌拉尔世晚期。在肃南组顶部发现的二齿兽类化石*Dicynodon sunanensis* (Li et al., 2000), 后被修订为博格达吐鲁番兽*Turfanodon bogdaensis* (Kammerer et al., 2011), 时代应该是乐平世晚期。在肃南组下部混生的华夏和安加拉混生植物群，时代是吴家坪期(Sun K Q et al., 2010)。故青头山组与肃南组之间可能缺失了部分卡匹敦期的沉积(图1)。

2.3 华北区

传统上华北区二叠系和三叠系的典型剖面由下到上为太原组、山西组、下石盒子组、上石盒子组、孙家沟组、刘家沟组、和尚沟组、二马营组、铜川组、永坪组和瓦窑堡组。

本区利用LA-ICP-MS对碎屑锆石进行分析的剖面有太原西山(Liu C et al., 2014; Sun et al., 2014)、河北平泉(Ma et al., 2011; Wei et al., 2015)以及河北承德下板城(Meng et al., 2014)。在承德县石湖村一带 “二马营组” 上部有火山凝灰岩夹层，LA-ICP-MS锆石U-Pb年龄加权平均值为(234.2±2.6) Ma (Zhang Y Q et al., 2016)。此外在黄河沿岸的二马营组及铜川组中有多层火山凝灰岩夹层，进行了LA-ICP-MS, SHRIMP以及CA-TIMS测年(Liu et al., 2013; 2018; Wang et al., 2014; Zhang et al., 2014; 2017)。因为方法的误差太大，下面不讨论采用LA-ICP-MS的测年结果。

太原组主要是海陆交互相，传统认为其时代是晚石炭世到早二叠世，不过石炭-二叠系的具体界线位置尚有争议。因为二叠系的底界以牙形刺*Streptognathodus isolatus*的首次出现来定义，王成源和康沛泉(Wang and Kang, 2000)认为太原组的时代为二叠纪，其中庙沟灰岩的底界非常接近二叠系的底界。不过这里的太原组是狭义的，没有包括晋祠砂岩，与王志浩和祁玉平(Wang and Qi, 2003)文章中的太原组含义相当。太原组顶部在河南、山东等地都发现了*Sweetognathus whitei*带，其时代为隆林阶(Wang and Qi,2003), 或者是亚丁斯克阶(Mei and Henderson, 2001)。

山西组为滨海和内陆沼泽沉积，一般不含灰岩夹层；不过太原西山的山西组主要为海相沉积。山西组对应于船山统到阳新统下部(相当于乌拉尔统上部) (Jin et al., 2000)。根据包含的*Caulopteris wudaensis-Paratingia datongensis*组合，在贺兰山北段其时代为早二叠世晚期，相当于萨克马尔期和亚丁斯克期(Sun and Deng, 2003)。根据孢粉组合，山西保德的山西组对应于亚丁斯克阶的一部分(Liu et al., 2015)。这里将山西组大致对应于亚丁斯克阶上部。

下石盒子组主要为河流和冲积平原沉积，根据植物化石认为相当于阳新统中部(大

致相当于乌拉尔统上部到瓜德鲁普统中下部) (Jin et al., 2000)。根据孢粉组合，其时代大致相当于空谷阶到沃德阶的一部分(Liu et al., 2015)。

上石盒子组时代是瓜德鲁普世晚期到乐平世早期。目前在河南济源本组近顶部发现的四足动物组合时代大致与南非的小头兽带相当，故其上界大约是255 Ma (Rubidge et al., 2013; Liu J et al., 2014), 也就是大约到吴家坪期结束。最近笔者在本组上部发现了火山凝灰岩层，对其进行测年可以检验这个结论。在北部边缘区的内蒙古于家北沟组是海陆交互相，有蜓类、苔藓类、双壳类和腕足类等海相化石以及多层火山凝灰岩层。其时代根据海相化石确定为瓜德鲁普世(Sun et al., 2016)。其植物群为*Gigantonoclea hallei-Fascipteris* spp.-*Lobatanularia heianensis*植物组合，亦可佐证上石盒子组地质时代。

孙家沟组主要是陆相沉积，但是在河南等地有海相夹层，在陕西渭北地区相变为海相沉积。其时代一般认为是乐平世晚期(Liu et al., 2011, 2015), 但是也有人认为是早三叠世(Yin and Lin, 1979)。在山西的孙家沟组发现过多层锯齿龙类化石，在柳林北沟锯齿龙类层位位于本组近顶部(Gao, 1983)。锯齿龙类在全球都被认为是二叠纪的类群，其在南非最后出现低于界线24 m, 没有延续到三叠纪(Benton, 2016; Viglietti et al., 2016)。故目前脊椎动物证据不支持二叠系与三叠系的界线明显低于孙家沟组与刘家沟组的界线。

刘家沟组以砂岩为主，化石比较稀少，在山西沁水盆地发现了交城肋木(*Pleuromeia jiaochengensis*) (Wang and Wang, 1982), 说明其时代为早三叠世。此外本组还发现过四足动物化石的碎片(李锦玲个人通讯); 说明即使在当时高温的环境下(Sun et al., 2012), 四足动物依然能够生存。

和尚沟组时代通常被认为是早三叠世晚期，主要依据是肋木属(*Pleuromeia*)化石的发现(Wang et al., 1978)。本组顶部以及二马营组底部产出陕北肯氏兽动物群，可以与犬颌兽B亚带对比，其时代被认为是早三叠世晚期，故将早中三叠世界线置于二马营组内部(Sun, 1980)。Lucas (1998, 2010)一直持这种观点，而Ochev and Shishkin (1989), Shishkin et al. (1995)和Rubidge (2005)则倾向于认为犬颌兽B亚带是安尼期。Ottone et al. (2014)在阿根廷的Quebrada de los Fósiles组顶部用SHRIMP得出(235.8 ± 2.0) Ma的年龄，并认为犬颌兽B亚带年龄更新，应该是卡尼期。这与二马营组二段下部243.5 Ma的测年结果不符，这里不采用。二马营组的测年结果支持早中三叠世分界位于和尚沟组内部的假说(Liu et al., 2018)。

二马营组分布在鄂尔多斯地层小区和晋-豫西地层小区，其时代通常被认为是中三叠世早期(安尼期) (Yang et al., 2000)。根据中国肯氏兽动物群与犬颌兽C亚带对比，认为其时代应该是安尼期晚期(Rubidge, 2005)。最近CA-TIMS测年在二段下部得到243.53 Ma的年龄，支持这一结论(图1⑤) (Liu et al., 2018)。河北下板城-平泉一带一套河流相红色砂泥岩组合，曾经被认为也是二马营组(Lu and Dou, 1982)。最近根据LA-ICP-MS测年结果，认为这套地层时代是晚三叠世(Meng et al., 2014; Wei et al., 2015; Zhang Y Q et al., 2016), 与命名地点差异太大，故有人建议恢复使用胡杖子组的名称(Wei et al., 2015)。由于方法本身的局限，这一年龄还需要用更好的测年方法来检验。不过这套地层的时代与鄂尔多斯盆地的二马营组没有多大关系。

铜川组是从原来的延长群一二段而来，是由中国地质科学院地质所于1965年命名，命名剖面位于陕西铜川漆水河金锁关，时代一般被认为是中三叠世晚期(拉丁期)。在铜川组二段二带下部有凝灰岩标准层，根据SHRIMP测年结果可能是拉丁期(Liu et al., 2013), 最近CA-TIMS得出了241.48 Ma的更精确的年龄(图1⑥) (Liu et al., 2018)。在最顶部的油页岩有大量的凝灰岩层，根据SHRIMP得出了(241.3±2.4)和(239.7±1.7) Ma的结果，王多云等提出狭义的延长组包含了中三叠统(Wang et al., 2014)。相应地，永坪组(原来的永坪组指延长群四段，这里采用《全国地层多重划分对比研究：陕西省岩石地层》(1998), 包括了原来的胡家村组，对应于延长群第三四段)。时代应该包括拉丁期及卡尼期。瓦窑堡组相当于原来延长群第五段，通过植物群对比，这套地层缺乏三叠纪最晚期，可能为诺利期左右。

2.4 华南区

中国南方的二叠系和三叠系以海相为主，但在二叠纪和三叠纪之交，在康滇古陆边缘有陆相以及海陆交互相沉积，在三叠纪中期有海陆交互相以及陆相地层(如巴东组), 在晚期转变为陆相含煤地层(如须家河组)。

黔西滇东一带二叠纪和三叠纪之交陆相地层(含海陆交互相)由下而上包括宣威组、卡以头组以及东川组。根据出产的大羽羊齿植物群，宣威组时代为乐平世(晚二叠世); 其整合或者假整合于峨眉山玄武岩之上，近来确定的峨眉山玄武岩喷发时间大约为260 Ma (Li et al., 2014), 说明其底界与乐平统下界基本一致。曾经根据岔河剖面68层中的锆石SHRIMP测年结果，认为宣威组顶部与煤山剖面的28层等时(Yu et al., 2008); 后来用ID-TIMS测定的年龄为(252.30±0.07) Ma, 与煤山剖面的25层年龄一致(Shen et al., 2011)。

卡以头组处在海陆过渡位置，既有海相的，又有海陆过渡相的，也有纯陆相的。它也是二叠纪和三叠纪的过渡层位，其具体时代颇具争议，如：早三叠世最早期(Chen et al., 2011; Liu and Yao, 2002), 从乐平世延续到早三叠世(Wang, 2001; 2002)。由于岩石地层的穿时性，不同剖面的卡以头组具体时代并不一定相同，需要具体情况具体分析：岔河和官坝冲剖面是长兴期晚期，而鲁贝剖面则从长兴期延续到印度期(Zhang H et al., 2016)。相应地，东川组的时代基本为早三叠世，但是在有些地方可能延伸到二叠纪最晚期。不过也有研究者基于对这些剖面和一些新剖面的研究，提出卡以头组时代都是从乐平世延续到早三叠世(Chu et al., 2016, 2017)。

巴东组二段以陆相为主，产出芙蓉龙以及远安鲵(Zhang, 1975; Liu and Wang, 2005; Liu, 2016)。巴东组时代一直有争议，曾经被全部归入安尼期或者拉丁期，后来又被认为是中三叠世(安尼期到拉丁期), 而在《中国地层典：三叠系》中被认为是安尼期。虽然有菊石等海相化石发现，但是与建阶地区的化石难以对比，这也是引起争议的原因。安尼期的年龄与古地磁研究的结果基本一致(Huang and Opdyke, 2000)。最近我们对碎屑锆石进行了分析，结论是晚于拉丁期(Hagen et al., 2018)。不过因为方法(LA-ICP-MS)制约，这个年龄可信度并不高。

四川盆地的须家河组有丰富的植物化石，也发现了我国最早的恐龙脚印。其下伏的小塘子组根据海相双壳类确定为诺利期，其时代大致确定为瑞替期。不过与其植物群

面貌相同的湖北的沙镇溪组，滇中普家村组、干海子组和舍资组时代被认为是诺利期到瑞替期(Yang et al., 2000), 而湖南桑植的鹰咀山组被认为是诺利期中晚期。用碎屑锆石大致确定其时代为三叠纪晚期，另外主要通过磁性地层学以及天文旋回地层的研究，与意大利以及美国Newark盆地的地层进行了对比，得出了其时代是三叠纪最晚期瑞替期的结论(Li et al., 2017)。

近二十年随着测年手段的提高，已经取得了一些进展，大致建立了中国二叠–三叠纪地层的年代框架，不过很多地层时代的认识还达不到阶这个级别。对于更精细的年代地层界线研究，就更加困难。在研究中最受关注的陆相二叠系和三叠系界线在华北和新疆还没有取得实质性的进展，还需要进行更多高精度的测年来解决陆相地层的时代问题。

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